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The anomalous suppression of $\pi_2(1670) \to b_1(1235)\,\pi$

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We show that current experimental data indicate that the strong decay mode $\pi_2 \to b_1\pi$ is anomalously small (more than 3 times smaller than all other decay modes of the π_2). This acts as a powerful discriminator for and against various decay models. Non-relativistic quark models with spin-1 pair creation, e.g. $^3P_0$ (flux-tube breaking) and $^3S_1$ and $^3D_1$ (chromo-electric string-breaking) models, as well as lowest order one-boson (in this case π) emission models, can accommodate the experimental data because of a quark-spin selection rule. Models that violate the selection rule, e.g. higher order one-boson emission decay mechanisms, as well as mixing with other Fock states and relativistic effects, may be constrained by the small $\pi_2 \to b_1\pi$ decay.

1. Experimental data on $\pi_2(1670) \to b_1(1235)\,\pi$

Recently, the VES Collaboration published for the first time an upper bound on the branching fraction $\mathrm{Br}[\pi_2 \to b_1\pi] < 0.0019$ at the 97.7% confidence level. This branching fraction is measured in 37 GeV π^- collisions on a nucleus, in the reaction $\pi^- A \to \omega\pi^-\pi^0 A^*$ [1]. This small branching fraction is consistent with preliminary data on the reaction $\pi^- p \to \omega\pi^-\pi^0 p$ in 18 GeV π^- collisions on a proton from the E852 Collaboration [2].

The decay $\pi_2 \to b_1\pi$ is allowed by conservation of parity, angular momemtum, charge conjugation, isospin and G–parity, and its strength should be compared with that of other decays which are allowed by the same quantum numbers, which are to an extraordinary degree conserved by the strong interactions. In order to show that the branching ratio is small for dynamical reasons, independent of any model, factors due to phase space and flavor should be removed. The standard expression of the partial width is [3]

$$\Gamma = \frac{p}{8\pi\,(2J_{\pi_2}+1)\,m_{\pi_2}^2}\,|p^L f \mathcal{M}|^2 \tag{1}$$

where m_{π_2} and J_{π_2} are the mass and angular momentum of the decaying π_2, the decay momentum p is measured in the rest frame of the π_2, L is the relative orbital angular momentum of the decay products, and $p^L f\mathcal{M}$ is the decay amplitude. The amplitude without the phase space (p^L) and flavor (f) factors is labeled $\mathcal{M}$. In Table 1 we show the ratio of $|\mathcal{M}|^2$ for the measured decay modes of the π_2 to $|\mathcal{M}|^2$ for the dominant decay mode ($f_2\pi$). A further refinement is to incorporate the usual suppression at large

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Table 1
Partial widths with phase space and flavor removed relative to the dominant mode. Decay is assumed to happen in the bold–faced L–wave, since in all modes (except for $f_2\pi$ where the D–wave is $(0.18 \pm 0.06)^2 = (3.2 \pm 2.2)\%$ of the S–wave [3]) the contributions from the different partial waves are not known. Define the ratios $R(X) = |\mathcal{M}(X)|^2 \;/\; |\mathcal{M}(f_2\pi)|^2$ and $\tilde{R}(X) = |\tilde{\mathcal{M}}(X)|^2 \;/\; |\tilde{\mathcal{M}}(f_2\pi)|^2$. The branching ratios do not add to unity, since ref. [3] only constrained some of the modes to add to unity. However, since $R(X)$ and $\tilde{R}(X)$ only measure relative branching ratios this is irrelevant to our conclusions.

Mode X	p (GeV)	L	f^2	$Br(\pi_2 \to X)$ (%) [3]	$R(X)$	$\tilde{R}(X)$
$f_2\pi$	0.326	**S, D, G**	2	56.2 ± 3.2	1.00	1.00
$\sigma\pi$	0.634	**D**	2	13 ± 6	0.73	1.00
$\omega\rho$	0.308	**P**, F	2	2.7 ± 1.1	0.53	0.53
$\rho(1450)\pi$	0.143	**P**, F	4	< 0.36	< 0.36	< 0.33
$\rho\pi$	0.649	**P**, F	4	31 ± 4	0.33	0.46
$K\bar{K}^*$	0.450	**P**, F	2	4.2 ± 1.4	0.27	0.30
$b_1\pi$	0.363	**D**	4	< 0.19	< 0.09	< 0.09

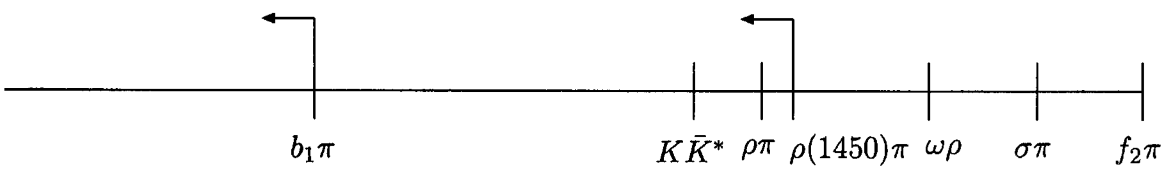

Figure 1. The results of Table 1 ($R(X)$) plotted logarithmically.

momenta, i.e. $\mathcal{M} = \exp(-\frac{1}{12}(\frac{p}{\beta})^2)\,\tilde{\mathcal{M}}$, where $\beta = 0.4$ GeV [4]. Table 1 also indicates these refined squared amplitude ratios. It is evident that the $b_1\pi$ mode is suppressed by a factor of between 3 and 11 relative to the other modes, making it anomalously small. Since there is only an experimental upper bound on the $b_1\pi$ mode, this suppression factor could be even larger, and we urge future experiments to put more restrictive bounds on this mode. An anomalously small mode will be distinctive on a logarithmic plot. As can be seen from Fig. 1, this is indeed the case.

2. Models that can accommodate $\pi_2(1670) \to b_1(1235)\,\pi$

The decay $\pi_2 \to b_1\pi$ is particularly clean in the sense that it is only sensitive to OZI allowed decays (see Fig. 2). This is because OZI forbidden processes, which allow the creation of either the isovector π_2, b_1 or π out of only isoscalar gluons, are forbidden to the extent that isospin is conserved.

In non-relativistic quark-pair-creation models, where the OZI allowed decay process is modeled by an initial meson $q\bar{q}'$ pair decaying to the two final meson pairs $q\bar{Q}$ and $Q\bar{q}'$, a simple selection rule arises when all the mesons have quark-spin 0. If the pair creation of the $Q\bar{Q}$ pair is with quark-spin $S = 1$, then conservation of quark-spin implies that the amplitude is zero. It can argued that the decay $\pi_2 \to b_1\pi$ is the only kinematically allowed decay involving experimentally discovered non-radially-excited mesons that can

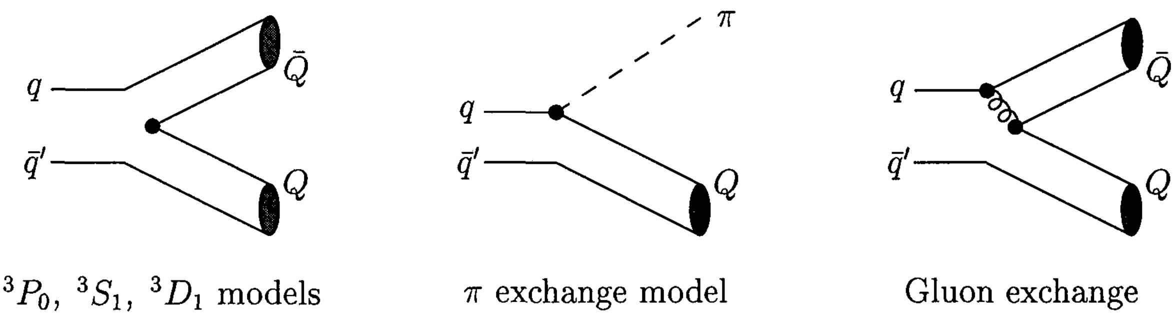

Figure 2. The OZI allowed decay of an initial meson to two final mesons in various models.

test the selection rule.

It has been pointed out that a success of the non-relativistic flux-tube breaking model, where the created quark-antiquark pair has $^3P_0$ quantum numbers (Fig. 2), i.e. $S = 1$, is the fact that $\pi_2 \to b_1\pi$ is predicted to vanish due to the selection rule [5]. Other decay models where the created pair has $S = 1$, such as the non-relativistic chromo-electric string-breaking model where the pair has $^3S_1$ or $^3D_1$ quantum numbers (Fig. 2) [6], will also have this suppression. Both the $^3P_0$ and $^3S_1$ models involve a decay operator proportional to $\vec{\sigma}\cdot\vec{p}$, with $\vec{\sigma}$ the Pauli matrices and $\vec{p}$ a momentum operator.

While the flux-tube and chromo-electric string-breaking models have a $q\bar{q}'$ pair decaying to the two final meson pairs $q\bar{Q}$ and $Q\bar{q}'$, one of which is identified with the pseudoscalar boson, the one-pion emission model (Fig. 2) has either $q \to Q\pi$ or $\bar{q}' \to \bar{Q}'\pi$. An expansion of the axial current in the lowest order one-boson coupling to the quark or antiquark gives a decay operator of the form $\vec{\sigma}\cdot\vec{p}$ (Eqs. 2 and 28 or ref. [7]). This means that the boson is created from the quark with $S = 1$, so that the selection rule would also be valid for lowest order one-boson emission.

We conclude that the phenomenologically successful pair-creation model for light-light mesons (the $^3P_0$ model) [5], the chromo-electric string-breaking model ($^3S_1$ or $^3D_1$ model), and the lowest order one-boson emission model, which has successfully been applied to the decay of heavy-light mesons [7,8], are consistent with the experimental decay width of $\pi_2 \to b_1\pi$.

3. Models possibly constrained by $\pi_2(1670) \to b_1(1235)\,\pi$

Higher order contributions in boson emission models do contain terms that are not of the form $\vec{\sigma}\cdot\vec{p}$ which violate the selection rule. An example is interactions where *both* a pseudoscalar boson is emitted, *and* a particle is exchanged between the quark and antiquark in the initial meson (Eqs. 13, 38 and 39 or ref. [7]). The amplitudes corresponding to the higher order contributions can be similar in magnitude to those corresponding to the lowest order contribution (Table 4 of ref. [7]). We hence suggest that consistency with the small decay $\pi_2 \to b_1\pi$ can be constraining for models which do not obey the selection rule, e.g. higher order contributions in one-boson emission models, and can provide a viability check on new decay mechanisms, e.g. the higher order contributions that were introduced [7] to cure problems with the lowest order contribution [7,8]. Although one-gluon exchange (Fig. 2) violates the selection rule away from the non-relativistic limit,[2] it was found to be subdominant relative to the $^3P_0$ model [9], so that it is not expected to be constrained by $\pi_2 \to b_1\pi$. If higher order contributions in boson emission models are inconsistent with $\pi_2 \to b_1\pi$, and one-gluon exchange is consistent, this could discriminate against the use of the boson exchange model.

4. Further constraints due to $\pi_2(1670) \to b_1(1235)\,\pi$

The selection rule obtains when the π_2, b_1 and π are treated non-relativistically as quark-spin 0 mesons. In addition to decay models in the previous section, further breaking of the selection rule arises from:

- *Mixing with other Fock states:* The mixing of mesons participating in the decay with non-meson Fock states is constrained by the experimentally measured $\pi_2 \to b_1\pi$ width. Examples of such mixing are: mixing between the quark-spin 0 π_2 meson and the quark-spin 1 π_2 hybrid meson expected nearby in mass, and non-mesonic Fock states in the Goldstone boson π.
- *Relativistic effects:* Relativistic corrections to the description of the mesons, which can introduce quark-spin 1 components in the π_2, b_1 and π mesons, are constrained by the experimentally measured $\pi_2 \to b_1\pi$ width. We urge fully relativistic lattice QCD, QCD sum rule and Dyson-Schwinger Equation calculations of $\pi_2 \to b_1\pi$.

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[2] One-gluon exchange involves both a Coulomb and transverse interaction. The former has a simple $\vec{\sigma}\cdot\vec{p}$ pair creation operator, but the latter involves *both* $\vec{\sigma}$ pair creation and an additional term at the vertex where the quark or antiquark emits a gluon in Fig. 2 (Eqs. B5-B7 of ref. [9]). The additional term includes a $\frac{1}{m}\,\vec{\sigma}\cdot\vec{p}$ contribution [9], which would mean that the overall transverse gluon interaction includes $S = 1$ contributions at *both* interaction vertices of the gluon, giving rise to a violation of the selection rule.

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